E-BEAM TRIODE FOR MULTIPLE SUBMICROSECOND PULSE OPERATION*

H. Harjes, K. Schoenbach, G. Schaefer,
H. Krompholz, and M. Kristiansen
Department of Electrical Engineering
G. Leiker and L. Hatfield
Department of Physics
Texas Tech University
Lubbock, Texas 79409

ABSTRACT

Externally controlled diffuse discharge switches offer the potential of submicrosecond opening time and high repetition rate. For the investigation of an electron-beam controlled diffuse discharge, an e-beam gun was constructed which allows submicrosecond, multiple pulse operation. The 200 kV, 100 cm^2, e-beam with thermionic cathode is designed as a triode. The control grid is pulsed to generate several successive e-beam pulses of ~ 100 ns duration and variable pulse-to-pulse interval. Electrical and optical diagnostics are used to monitor the triode performance. Preliminary switch experiments in N_2-O_2 gas mixtures are discussed.

I. INTRODUCTION

In recent years there has been an increasing interest in the development of fast, repetitive, opening switches which would allow the use of inductive energy storage in repetitivly operated pulsedpower systems. An opening switch concept that shows promise for fast repetitive operation is the electron beam (e-beam) controlled switch (EBCS). Such a switch is depicted in the simple inductive energy storage circuit of Fig. 1. The switch electrodes are separated by a pressurized gaseous dielectric which conducts and charges the inductor when an ionizing e-beam is injected (usually through one of the electrodes which might be mesh or foil). The switch voltage remains below the self breakdown voltage so that there is negligible avalanche ionization in the switch gas. Thus, the discharge is completely sustained by the e-beam current. When the e-beam is turned off,electron attachment and recombination processes in the gas cause the discharge to die out and the switch opens. By commutating the repetitively operated EBCS with the second switch in the circuit of Fig. 1, a train of pulses can be delivered to the load until the inductor is discharged.

Obviously, the performance capability of such an inductive energy storage pulser is mainly dependent upon the performance capability of the EBCS. Consequently, one would like to have an EBCS that satisfies the following conditions:

1) high rep-rate capability
2) fast turn on and off capability
3) high current handling capability
4) high voltage standoff capability
5) high efficiency

Single shot EBCS's have been investigated by Hunter [1], Kovalchuk [2], Fernsler [3], Hallada [4], Kline [5], Commisso [6], and others. These investigations have demonstrated the promise of the EBCS in satisfying the above requirements. However, the only reported investigation into the repetitive operation of an EBCS has been theoretical [7]. These investigations also clearly indicate that the switch characteristics mentioned in the above list depend primarily upon the parameters of the switch gas. The switch gas mixture should have a high mobility and a low attachment rate at low values of E/N when the switch is conducting. This reduces conduction losses and increases the switch efficiency. The gas mixture should then have a low mobility and a high attachment rate at high values of E/N when the switch is opened to decrease the switch opening time [8]. Since only a few gas mixtures have been tried in previous EBCS experiments, there are probably several more suitable gas mixtures. Consequently, experimental investigations into the repetitive operation of an EBCS with promising candidate gas mixtures are needed.

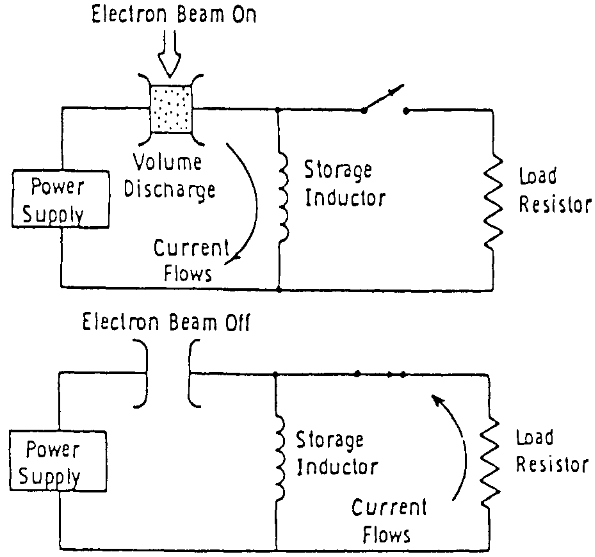

Figure 1. Schematic Diagram of Electron Beam Switch Operation [9].

The e-beam triode that will be described in this paper was specifically designed to deliver a controllable e-beam for such an EBCS experiment. The purpose of the experiment is to study the repetitive operation of the switch under a wide range of gas and e-beam parameters. Consequently the e-beam has to satisfy the following requirements:

1) high repetition rate
2) fast turn on and turn off times
3) variable beam energy and current density.

The e-beam gun is constructed as a triode to achieve the required repetitive, fast response control of the e-beam and a thermionic cathode is used to satisfy the last condition. In the second section of this paper, the triode, the grid pulser, and the switch are described in detail. In the third section, the results of the triode operation and some preliminary switching results are presented. In the last section, a summary is given.

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Externally controlled diffuse discharge switches offer the potential of submicrosecond opening time and high repetition rate. For the investigation of an electron-beam controlled diffuse discharge, an e-beam gun was constructed which allows submicrosecond, multiple pulse operation. The 200 kV, 100 cm2, e-beam with thermionic cathode is designed as a triode. The control grid is pulsed to generate several successive e-beam pulses of - 100 ns duration and variable pulse-to-pulse interval. Electrical and optical diagnostics are used to monitor the triode performance. Preliminary switch experiments in N2-02 gas mixtures are discussed.

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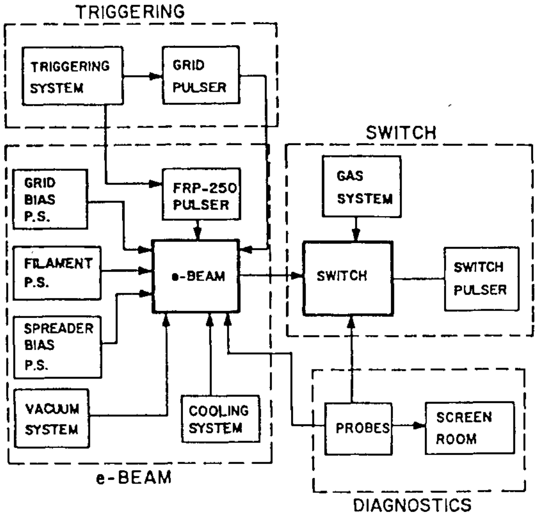

Figure 2. Block Diagram of EBCS Experiment.

II. EXPERIMENTAL ARRANGEMENT

A block diagram of the experiment is shown in Fig. 2. Most of the subsystems shown in the block diagram are common in pulse power experiments, so the descriptions that follow will concentrate on the triode, the pulser that drives the triode control grid and the switch.

A crossection of the e-beam triode and the switch chamber is shown in Fig. 3. The e-beam cathode is located in an evacuated pyrex cylinder between the two plates of a stripline (Fig. 3). The bottom plate of the stripline is grounded and the e-beam accelerating voltage is applied to the top plate by a two stage Marx generator. This pulser (FRP-250) can deliver a maximum voltage of 250 kV with a 10 ns rise time and with an exponential decay time constant of about 2 µs. As the accelerating voltage decays, the transmission of the e-beam through the foil window (between the e-beam and switch chambers) decreases. Consequently, with this pulser the e-beam is only effective during the first microsecond of operation.

A more detailed crossection of the cathode is shown in Fig. 4. The electron source is an electrically heated array of 15 mil diameter thoriated tungsten filaments. When the filaments are heated to a temperature of about 2100 K, 800 W of heating power is required and the resulting e-beam current density is about 4 A/cm^2 over the 100 cm^2 crossectional area of the beam. With a thermionic cathode, the e-beam current density can easily be varied independent of the accelerating voltage by simply adjusting the filament temperature.

The control grid is located just above the filament array and is formed by an array of 10 mil diameter molybdenum wires stretched across a 7 inch diameter circular hole in the outer shell of the cathode assembly. These two arrays are connected to external power supplies through high vacuum electrical feedthroughs located in the aluminum base of the cathode (Fig. 4). The base is water cooled and serves as a heat sink for the rest of the cathode.

The triode operates as follows. A sufficient negative bias voltage, V_B, is applied to the grid to hold the e-beam off even when the accerating voltage is applied to the plate. Then, the e-beam is turned

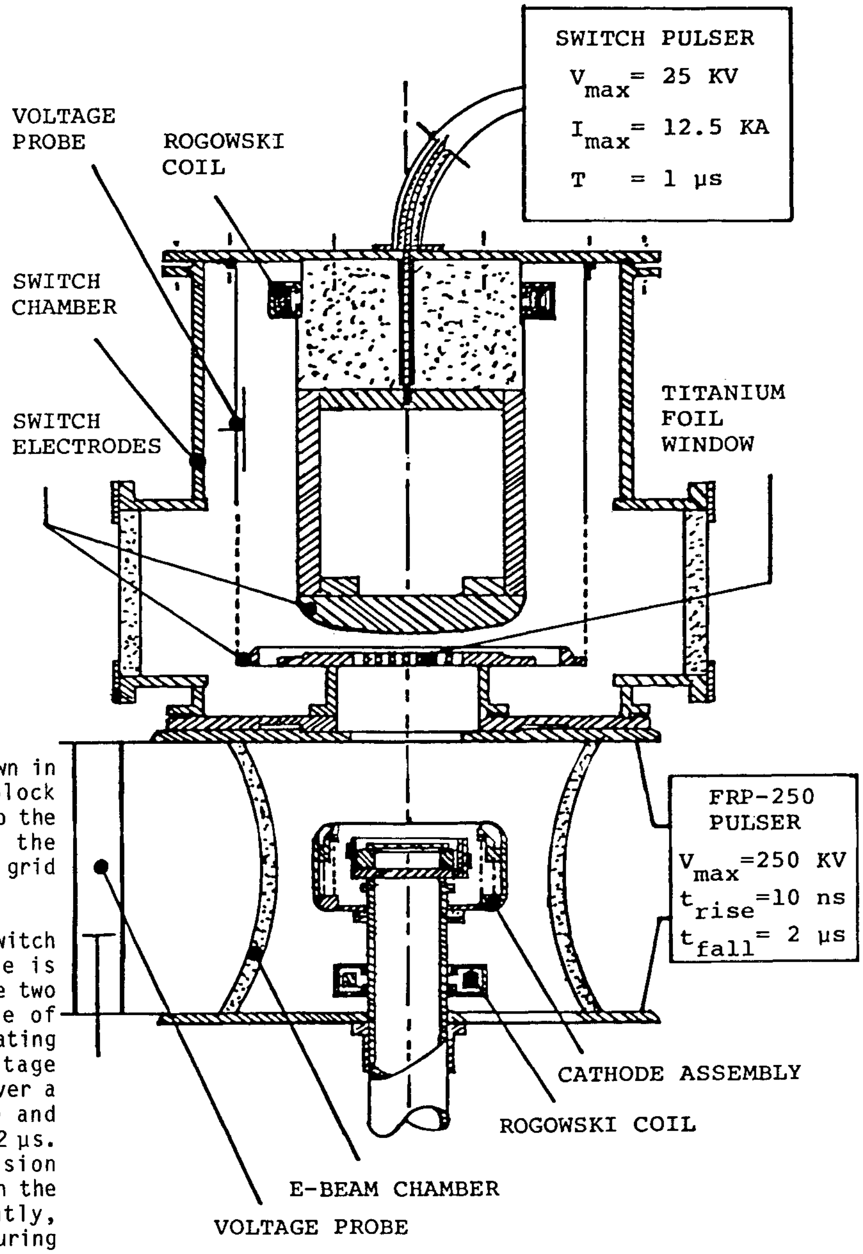

Figure 3. Crossection of Triode and Switch Chamber.

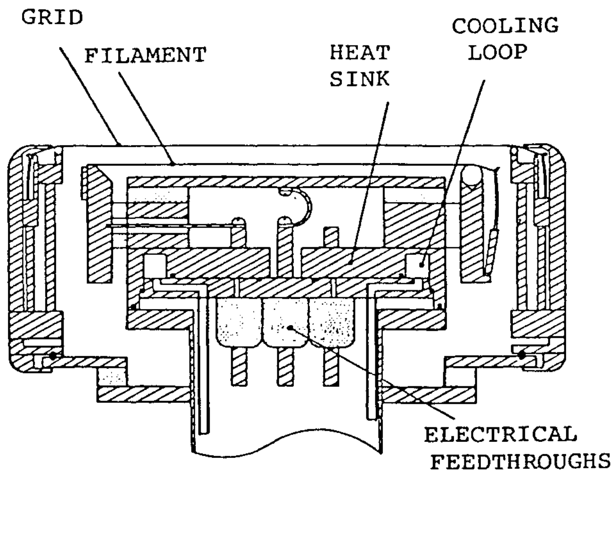

Figure 4. Crossection of Cathode Assembly.

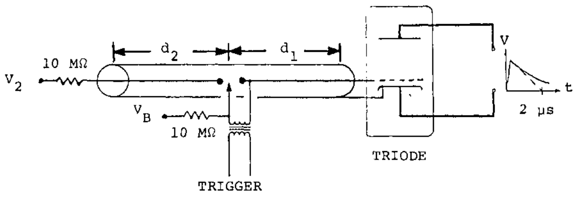

Figure 5. Schematic Diagram of Grid Pulser.

on by applying a positive voltage pulse to the grid. The pulser that drives the grid is depicted in Fig. 5. It consists of two, 75 Ω, coaxial cables separated by a triggerable coaxial spark gap. Cable 1 is connected to the grid as shown and is charged to V_B, (typically about -6 kV). Cable 2 is charged through a 10 MΩ charging resistor to V_2 (typically about 16 kV). When the gap is triggered, a positive voltage wave propagates from cable 2 along cable 1 to the grid. The grid is ideally an open circuit load to the cable so the wave is totally reflected. The grid voltage at this time changes rapidly from V_B to V_2 and the e-beam is turned on. The e-beam is later turned off again by the arrival of a negative voltage wave at the grid. This wave begins in cable 1, propagates along cable 2 to its essentially open end, is reflected, and then propagates to the grid. With the two open ends of this pulser, a train of positive and negative pulses is applied to the grid and the e-beam is repetitively turned on and off.

The primary advantage of this type of pulser is its overall simplicity. The pulse magnitudes are easily variable by changing the cable charging voltages and the pulse widths can be adjusted by simply changing the lengths of the cables. Obviously, this pulser cannot deliver a continuous train of unattenuated square pulses. Unavoidable losses present in the pulser (i.e. spark gap losses, capacitive loads at the ends of the pulser, etc.) will limit the useful length of the train to a finite number of pulses.

The switch is located in a pressurized stainless steel chamber just above the e-beam chamber, as shown in Fig. 3. The e-beam enters the switch chamber through a 1 mil thick Titanium foil window which separates the two chambers. After entering the switch chamber, the e-beam passes through the lower electrode of the switch which is a 1/2 mil thick aluminum foil and is incident on the stainless steel upper electrode. The e-beam ionizes the gas between the two switch electrodes and generates a diffuse discharge. The two electrodes are connected coaxially to the switch pulser, as shown. This pulser is a 2 Ω PFN that is able to deliver a 25 kV, 12.5 kA, 1 µs pulse to a matched load.

The e-beam current is measured by a Rogowski coil located around the cathode feed tube, as shown in Fig.3. The e-beam accelerating voltage is monitored by a resistive voltage divider between the two plates of the stripline. A Rogowski coil around the inner conductor of the short coaxial section in the switch chamber is used to measure the switch current. The switch voltage is monitored by a capacitive voltage divider probe, as shown in Fig. 3. Since the switch diagnostics are floating at the switch chamber potential (i.e. the potential of the top plate of the stripline), it is necessary to electrically decouple these diagnostics from the recording system. Coupling is obtained through an analog optical link whose response time is better than 10 ns. Descriptions of this link and the Rogowski coils are given in Ref. 10

III. RESULTS

The output of the grid pulser when fired into a 100 KΩ load is shown in Fig. 6a. The rise and fall time on the first pulse is about 10 ns. There is significant degradation in the amplitude and in the rise/fall time of each subsequent pulse in the train due to the losses mentioned in the previous section.

When the triode is connected in the simple circuit of Fig 6b and the output of the grid pulser is applied to the grid, the e-beam current shown in Fig. 6c results. In this case the plate voltage was 30 kV, the filament temperature was about 2000 K, and the resulting peak current was 60 A. The output current follows the input grid voltage waveform (first pulse rise/fall time ~ 10 ns) demonstrating the expected

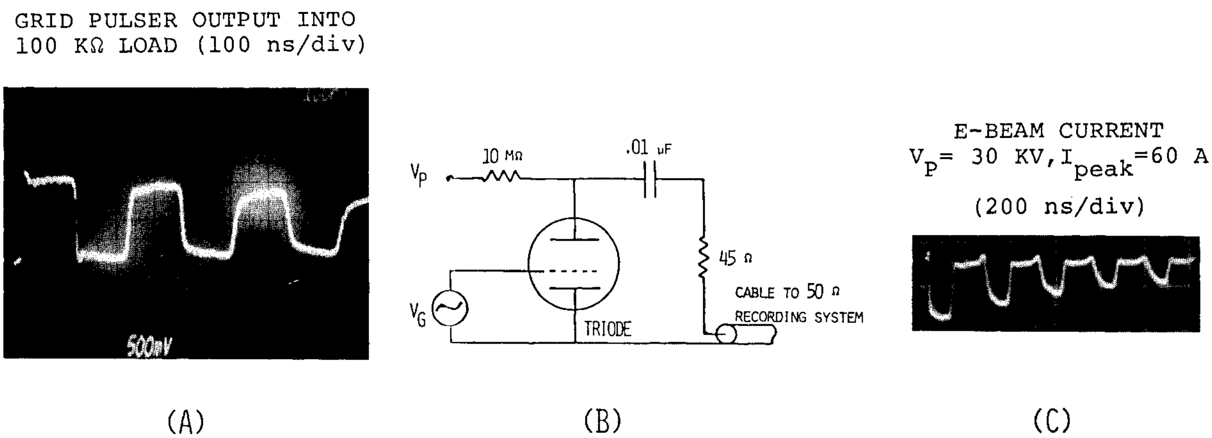

Figure 6. E-beam Results.

performance of the triode. The triode has been operated with plate voltages up to 240 kV, and filament temperatures up to 2100 K. The resulting beam current waveform is similar to the one of Fig. 6c with a peak value of about 400 A.

The results of some preliminary switching experiments in N_2:O_2 gas mixtures are shown in Fig. 7. These experiments were conducted to test the repetitive operation of the switch system, not to achieve optimum switch performance. In Fig. 7a, both the measured switch current waveform and the measured e-beam current waveform for one shot are shown. The experimental conditions for this shot are listed in the figure. Notice that the value of E/N is very small and there is no switch current gain in this case. In fact, the leading part of each switch current pulse is probably due to the collection of the corresponding incident e-beam current by the top electrode of the switch. The tail on each pulse is the component of the switch current caused by the ionization of the gas by the e-beam. This current is small because the electron drift velocity is small at low values of E/N. However, notice that the switch current turns off after each e-beam pulse (time constant ~ 100 ns) due to electron attachment processes in the N_2:O_2 gas mixture.

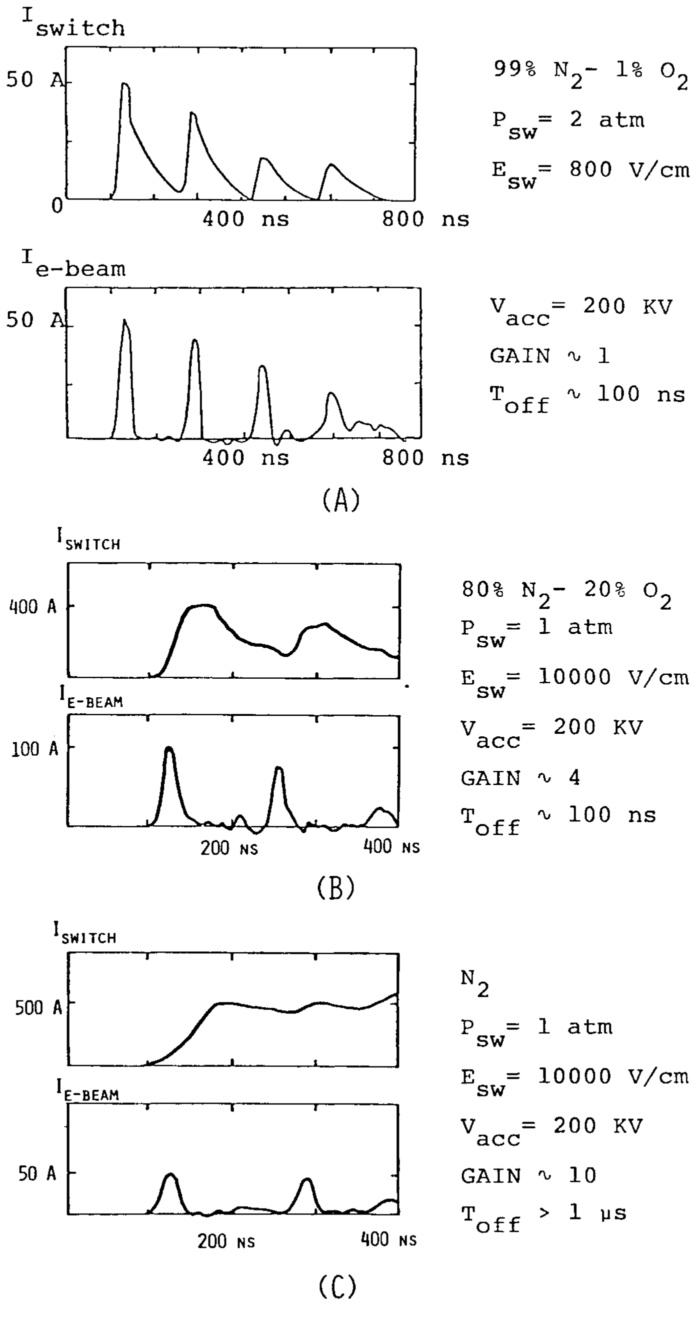

Figure 7. Preliminary Switching Results.

When the value of E/N is increased, the switch current waveform of Fig. 7b is observed. The experimental conditions are again listed in the figure. The e-beam input current waveform has the same shape as before but with a peak value this time of 100 A. In this case, a switch current gain of 4 is observed. The turn off time constant is, as before, about 100 ns.

In Fig. 7c, the effect of a slight change in the gas composition is demonstrated. In this case the concentration of the attacher, O_2, has been reduced to less than .1%. The other experimental parameters are essentially the same as before. The switch current waveform shows a slow decay with a turn off time constant in this case of greater than 1 μs.

IV. SUMMARY

An e-beam triode that is able to deliver a controllable, 240 keV, 400 A, 100 cm^2, e-beam for a EBCS experiment has been designed and tested. The triode is turned on and off with ~ 10 ns response times at variable rep-rates up to ~ 25 MHz in 1 μs bursts by a simple pulser. A coaxial switch driven by a 2 Ω PFN, has also been constructed. The objective of the experiment is to study the behavior of an e-beam sustained attachment dominated discharge, suitable for fast, low loss, rep-rated operation, at high discharge current densities in various gas mixtures.

Preliminary repetitive switch experiments in N_2:O_2 gas mixtures have been conducted. At a 5 MHz rep-rate, a switch current gain of 4 and a turn off time constant of ~ 100 ns was observed. These results do not represent optimized switch performance but do demonstrate that the repetitive EBCS experiment is operational.

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